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Competition and Innovation: An Experimental Investigation*

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Abstract: The paper analyzes the effects of more intense competition on firms' incentives to invest in process innovations. We carry out experiments based on two-stage games, where R&D investment choices are followed by product market competition. As predicted by theory, an increase in the number of firms from two to four reduces investments. However, a positive effect is observed for a switch from Cournot to Bertrand, even though theory predicts a negative effect in the four-player case.

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Keywords: R&D investment, intensity of competition, experiment.

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1 Introduction

Simple two-stage games are often used to derive predictions about the effects of the intensity of competition on cost-reducing investments.[1] The empirical test of these predictions is very difficult, and the literature comes to ambiguous conclusions.[2] Therefore, this paper uses laboratory experiments as a complementary research strategy to explore whether at least the basic strategic effects identified in the theoretical models are present in a laboratory setting.

Specifically, we consider four different games where two or four firms can choose a cost-reducing investment before they engage in Cournot or Bertrand competition. In this fashion, we can explore the effects of increasing competition both by increasing the number of players and by switching from Cournot to Bertrand competition. Thus, we can capture two of the most familiar notions of increasing competition. The predicted effect of competition on investment is unambiguously negative for an increase in the number of firms. For a shift from Cournot to Bertrand competition, the effect is mostly positive, except in the duopoly case for some parameter constellations, including one of the treatments we considered.

The experiments fully confirm the negative number effects.[3] For a switch from Cournot to Bertrand competition, however, the observed effect is always positive, even when the predicted effect is negative. This observation relates to how players deviate from the Nash equilibrium. In both cases, there is overinvestment. However, this overinvestment is more pronounced in the Bertrand case, so that there may be a positive effect of switching from Cournot to Bertrand even when theory predicts a negative effect.

Obviously, a simple set of experiments cannot resolve the century-old debate about the effects of competition on investment. First of all, there are too many conceptual ambiguities at the theoretical levels. Even the definition of increasing intensity of competition is contentious, some insightful attempts to structure the debate notwithstanding.[4] Second, even if one settles for

[1]Schmutzler (2007) and Vives (2008) synthesize the existing literature.

[2]See Gilbert (2006).

[3]Importantly, note that our analysis is distinct from the more familiar analysis of number effects in oligopolies (Huck et al. 2004; Orzen 2008, forthcoming). This literature deals with the effects on prices and quantities rather than on investments.

[4]Boone (2000) shows that many different measures of competition share the common property that increasing competition can be associated with a higher ratio of the profits

a specific notion of increasing competition in two-stage games, there is a bewildering variety of models to investigate the issue.[5] Third, of course, one can go beyond the two-sage setting and investigate more complicated dynamic models.[6] Finally, one may worry about the external validity of the laboratory setting as a means of testing predictions about the long-term strategic decisions of managers in (potentially large) firms.

In spite of all these cautionary remarks, we believe that the subsequent analysis leads to one important insight: Our laboratory analysis suggests that behavioral effects may imply a more positive effect of competition on investment than a purely theoretic analysis would reveal. Future work will have to show how robust these effects are in the lab. More importantly, perhaps, it will have to show whether the effect is also present in the field.

There are only few experimental studies which directly deal with the linkage between intensity of competition and R&D investments. Isaac and Reynolds (1988, 1992) consider the number effects. They deal with stochastic static and dynamic patent races and show that an increase in the group size lowers investment per firm and raises aggregate investment. We are not aware of experimental papers comparing Cournot to Bertrand competition. In Sacco and Schmutzler (2008), we analyze a two-stage Bertrand game, where investments precede price competition.[7] We show that overinvestment is substantial. However, there, we do not deal with the effects of increasing competition.[8]

The paper is structured as follows. Section 2 contains the theoretical

between more efficient and less efficient firms.

[5]Vives (2008) provides a unifying discussion of two-stage games, with the extent of product differentation as an inverse measure of competition. Schmutzler (2007) extends the discussion to other measures of competition.

[6]For instance, Lee and Wilde (1980) identify a positive effect of the number of firms on investment per firm in a Bertrand setting, whereas Delbono and Denicolò (1991) find a negative effect, even on total investment, in the Cournot case. In a stochastic patent race preceding product market competition, Delbono and Denicolò (1990) show that investment in the Bertrand case is unambiguously higher than in the Cournot case. Bester and Petrakis (1993) show that, with sufficiently large horizontal product differentiation, the innovation incentive is higher under Cournot competition than under Bertrand competition.

[7]Suetens (2005) considers investment games in a Cournot setting. However, she is not concerned with the effects of competition.

[8]The theoretical part of the paper deals more generally with all-pay auctions with negative prize externalities. The Bertrand investment game used in the experiment is a special case of the general set-up.

framework. Section 3 describes the experimental design and results. Section 4 concludes.

2 The Model

We analyze static two-stage games, where firms $i = 1, ..., I$ first invest in R&D and then compete in the product market. The demand function for the homogenous product is given by $D(p) = a - p$, with $a > 0$. All firms i are identical ex-ante with constant marginal costs $c > 0$. In the first stage, firms simultaneously choose R&D investments $Y_i \in [0, c)$, resulting in marginal costs $c_i = c - Y_i$.[9] The cost of R&D is given by kY_i^2, where $k > 0$. In the second stage, firms simultaneously choose quantities (Cournot) or prices (Bertrand). We refer to the Cournot case as soft competition (SC); to the Bertrand case as intense competition (IC).

2.1 Soft Competition

For SC, backward induction shows that the net payoff function of firm i in the first stage is given by

$$\Pi_i(Y_1, ..., Y_I, \alpha, k) = \left(\frac{\alpha + IY_i - \sum_{i \neq j} Y_j}{I+1}\right)^2 - kY_i^2, \tag{1}$$

where $\alpha \equiv a - c$ represents the demand parameter.[10]

The gross payoff of firm i, that is, the first term on the right-hand side of (1), depends positively on its own investment and the demand parameter, and negatively on the investments of the other firms. Competition is soft in the sense that even a firm that invests less than the others achieves a positive gross payoff, unless $Y_i \ll Y_j$.

Maximizing (1) with respect to Y_i yields

$$\frac{\partial \Pi_i(\cdot)}{\partial Y_i} = \frac{2I(\alpha + IY_i - \sum_{i \neq j} Y_j)}{(I+1)^2} - 2kY_i \equiv 0. \tag{2}$$

[9] Even though agents are restricted to finite strategy sets in the experiment, the theoretical analysis is much more transparent if the strategy set is a continuum.

[10] Here and in the following, we assume that $\alpha + IY_i - \sum_{i \neq j} Y_j \geq 0$.

We assume that the second order condition holds, that is,

$$\frac{\partial^2 \Pi_i(\cdot)}{\partial Y_i^2} = \frac{I^2}{(I+1)^2} - k < 0, \tag{3}$$

which is fulfilled for arbitrary $I \geq 2$ if $k > 1$.

The equilibrium follows immediately from (2).

Proposition 1 *Under SC the symmetric pure-strategy Nash equilibrium investment levels are*

$$Y^{SC} = \frac{\alpha I}{k(I+1)^2 - I}. \tag{4}$$

By (4), equilibrium investments are increasing in the demand parameter α, and decreasing in the cost parameter k and in the number of firms I.

2.2 Intense Competition

For IC, backward induction shows that the net payoff function of firm i in the first stage is given by

$$\Pi_i(\cdot) = \begin{cases} (Y_i - Y_{-i}^m)D(c - Y_{-i}^m) - kY_i^2, & \text{if } Y_i > Y_{-i}^m \\ -kY_i^2, & \text{if } Y_i \leq Y_{-i}^m \end{cases}, \tag{5}$$

where $Y_{-i}^m = \max_{j \neq i} Y_j$. Competition is intense in the sense that a firm can achieve a positive gross payoff only by investing more than the highest investment of the others. If $Y_i > Y_{-i}^m$, maximizing (5) with respect to Y_i gives

$$\frac{\partial \Pi_i(\cdot)}{\partial Y_i} = D(c - Y_j^m) - 2kY_i \equiv 0. \tag{6}$$

$Y_i \leq Y_{-i}^m$ can only be a best response if $Y_i = 0$ holds: If firm i does not invest more than all others, it gets a negative net payoff. In such a case the deviation to $Y_i = 0$ is profitable. The pure-strategy equilibrium is thus characterized as follows.

Proposition 2 *(i) Under IC, for $k > \frac{1}{2}$, there are multiple asymmetric pure-strategy equilibria with one firm investing $Y_i^{IC} = \frac{\alpha}{2k}$ and firms $j \neq i$ investing $Y_j^{IC} = 0$. (ii) There are no other pure-strategy equilibria.*

Proof. (i) If firms $j \neq i$ invest $Y_j^{IC} = 0$, then according to (6) the best response of firm i is $Y_i^{IC} = \frac{\alpha}{2k}$ for any $k > 0$. If firm i invests $Y_i^{IC} = \frac{\alpha}{2k}$, then the best response of the other firms is $Y_j^{IC} = 0$ for $k > \frac{1}{2}$. That is, firm j does not have an incentive to exceed the investment of firm i by choosing $Y_j^{IC} = \frac{\alpha}{2k} + \Delta$, where $\Delta > 0$. The value $\Delta = \frac{\alpha}{4k^2}$ maximizes $\Pi_j(\cdot)$ which is negative for $k > \frac{1}{2}$.
(ii) is immediate. ■

Thus, the average equilibrium investment level is given by

$$\overline{Y}^{IC} = \frac{\alpha}{2kI}, \tag{7}$$

which is increasing in the demand parameter, and decreasing in the cost parameter k and in the number of firms I.

It is unlikely that agents can coordinate on one of the asymmetric pure-strategy equilibria, in particular, because only the investor obtains positive payoffs. In the experimental analysis, we therefore refer to the following result of Sacco and Schmutzler (2008).

Proposition 3 *The IC-game has a symmetric mixed-strategy equilibrium, where firms mix between all strategies up to a cut-off level.*

In the companion paper, we also provide an algorithm for calculating this equilibrium.[11]

2.3 The Effects of Increasing Competition

We now show that, with a small qualification for the comparison between SC and IC, the predicted effects of competition on investment are negative.

Corollary 1 *For a given type of product market competition, SC or IC, the average equilibrium investments are decreasing in I.*

Similarly, comparing (4) to (7), the following result arises.

Corollary 2 *Suppose that (3) holds and $k > \frac{1}{2}$. The average equilibrium investment for SC is higher than the average investment in each asymmetric pure-strategy equilibrium for IC unless $I = 2$ and $k > 2$.*

[11] The game also has asymmetric mixed-strategy equilibria where some firms always play zero and others randomize.

Though we cannot provide such a result for the mixed-strategy equilibrium at this level of generality, a similar statement holds for the parameters we choose (see 3.1).

Thus, except for the caveat for $I = 2$, for both concepts of competitiveness, an increase in competition reduces investment.

3 The Experiment

3.1 Choosing the Parameters

We conducted four treatments. There were two sessions with two-player groups (SC2 and IC2) and four-player groups (SC4 and IC4), respectively.[12] Further, we chose $\alpha = 30$ and $k = 3$. In the experiments, we restricted the strategy sets to $Y_i \in \{0, 1, ..., 9\}$. It can be shown that the equilibria of the game with the discrete strategy set are $(2, 2)$ for SC2 and $(2, 2, 2, 2)$ for SC4. However, this prediction relies on an extremely mechanical application of the Nash equilibrium. It is straightforward to show that marginal investment incentives are higher for each player in SC2 than in SC4. Economic intuition therefore suggests that the effect of increasing the number of players should be negative.[13] This prediction is obtained if one views the players as playing a continuous game: In the Nash equilibrium of the continuous version of SC2, investments are higher than for SC4 ($2.4 > 1.69$).

Under IC, according to Proposition 2, there are asymmetric equilibria, each with one firm investing 5 and the other firm(s) 0. This holds both for the discrete and continuous strategy set. Moreover, according to Sacco and Schmutzler (2008), IC2 has a symmetric mixed-strategy equilibrium (MSE) given by

$$(p_0, ..., p_9) = (0.1, 0.193, 0.187, 0.182, 0.176, 0.160, 0, 0, 0, 0)\,. \tag{8}$$

For IC4, the symmetric MSE is given by

$$(p_0, ..., p_9) = (0.464, 0.2, 0.119, 0.088, 0.071, 0.057, 0, 0, 0, 0)\,. \tag{9}$$

[12] The results for IC2 are also reported in Sacco and Schmutzler (2008).

[13] Schmutzler (2007) formalizes this intuition. He gives general conditions under which an increase in the number of players (weakly) reduces the investments of players in an investment game. These conditions hold in the example.

The expected investment level is 2.62 for IC2 and 1.27 for IC4.[14]

3.2 Experimental Design and Procedures

The experimental sessions were conducted in June and November 2006 at the University of Zurich. The participants were undergraduate students.[15] To focus on investment choices, we reduced the games to the first stage, that is, to the investment stage. For each investment profile, players earned the unique Nash equilibrium payoffs of the corresponding subgame. Thus, we did not model the product market stage explicitly.[16] This allows us to avoid confusion about the source of possible deviations from the equilibrium in the investment game: Contrary to a two-stage experiment, investment decisions cannot be influenced by speculations about deviations from equilibria in the product-market stage.[17]

We implemented two sessions with IC treatments, and two with SC treatments. In each session there were 20 periods and in two of four sessions 36 subjects.[18] This led to a total of 2760 investment observations. No subject participated in more than one session. The participants were randomly matched into groups of size two or four after each period. This corresponds to a Stranger design.[19] At the end of each period, subjects were informed about the investment level of the other group member(s) and their own net payoff for that period. In each session, participants received an initial endowment of CHF 35 (≈EUR 22). Average earnings including the endowment were CHF 31 (≈EUR 19) for IC2 and CHF 32.50 (≈EUR 20) for IC4. The amounts for SC2 and SC4 were CHF 49 (≈EUR 31) and CHF 39 (≈EUR 24), respectively. Sessions lasted about 90 minutes each. The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007).

[14]Note that the expected investment levels are close to the average investments ($\overline{Y}^{IC2} = 2.5$; $\overline{Y}^{IC4} = 1.25$).

[15]We did not exclude any disciplines. We had students of law, engineering, psychology, economics etc.

[16]A similar strategy was pursued in the Cournot investment experiments of Halbheer et al. (2007). Sacco (2008) compares the behavior of subjects in a two-stage experiment with behavior in the corresponding reduced-form game.

[17]Such deviations are known to arise both in the Bertrand case (Dufwenberg and Gneezy, 2000) and in the the Cournot case (Huck et al. 2004, and many others).

[18]In the SC4 and IC2 sessions there were 32 and 34 participants, respectively.

[19]Observe that through the choice of a Stranger design the experimental analysis is based on one-shot considerations.

3.3 Results

Based on the results of sections 2.3 and 3.1, we test the following hypotheses.

Hypothesis 1 Investments are lower in SC4 than in SC2.

Hypothesis 2 Investments are lower in IC4 than in IC2.

Hypothesis 3 (a) Investments are lower in IC4 than in SC4. (b) Investments are higher in IC2 than in SC2.

That is, we first consider the effects of increasing the number of players. The analysis of the SC treatment (Hypothesis 1) precedes that of the IC treatment (Hypothesis 2). Second, for a given number of players, we consider the effects of switching from SC to IC (Hypothesis 3).

3.3.1 Soft Competition

The mean investments over all periods and subjects are 2.59 and 1.83 for SC2 and SC4, respectively. These are slightly above, but very close to the equilibria of the continuous version of the SC game. Hence, in spite of the discrete formulation of the game, the continuous game may provide better predictions than the discrete game, which, to repeat, predicts average investments of 2 in both cases. This point is interesting beyond the specific game.

Result 1 *Mean investments are higher for SC2 than for SC4.*

Considering all periods, both a regression over a constant and a Wilcoxon rank sum test show that the difference between the two treatments is highly significant ($p < 0.01$). This also holds in the last five periods. That is, the mean investment level under SC2 does not converge to that under SC4.

Figure 1 reveals that there is overinvestment for SC2 and underinvestment for SC4 if one takes the equilibrium of the discrete game as the benchmark.[20] Relative to the equilibrium of the continuous game, there is overinvestment

[20] In SC2, the difference between investments and Nash equilibrium is highly significant over all periods. This also holds in the last five periods. In SC4, the difference with respect to the prediction is likewise highly significant throughout the 20 periods. Interestingly, this also holds in the last five but not in the first five periods.

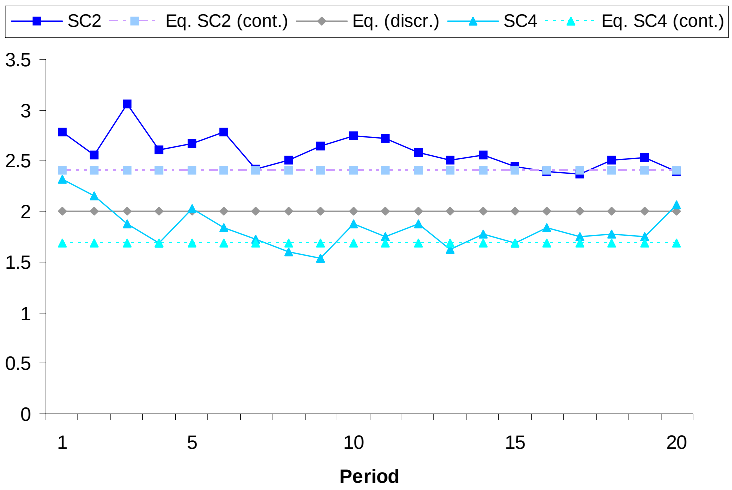

Figure 1: Mean investments under SC.

in both cases. Over all periods, the difference between observed investments and corresponding continuous benchmark is highly significant. However, in the last five periods, the difference is significant only for SC4 ($p = 0.017$).

While the main objective of this subsection was the test of Hypothesis 1, we also note in passing that investments are concentrated around the equilibrium (see Figure 2).

Result 2 *For SC2, 77% of the investments over all periods are either 2 or 3. For SC4, 80% of the investments are either 1 or 2.*

Also, the concentration around the equilibrium arises in almost every single period.[21]

Finally, the concentration of investments around the equilibrium is also reflected in the average investments of each player.

For each interval of length 1, Table 1 gives the number of subjects whose average investment is in the interval. For SC2, 28 of the 36 subjects choose

[21] Under SC2, the investment level of 2 is chosen most often in 17 periods, followed by 3. In the remaining three periods, 3 is the most frequently played investment level, followed by 2. Under SC4, again in 17 periods, 2 is chosen most often, followed by 1. In the other three periods, 1 is played most often, followed by 2.

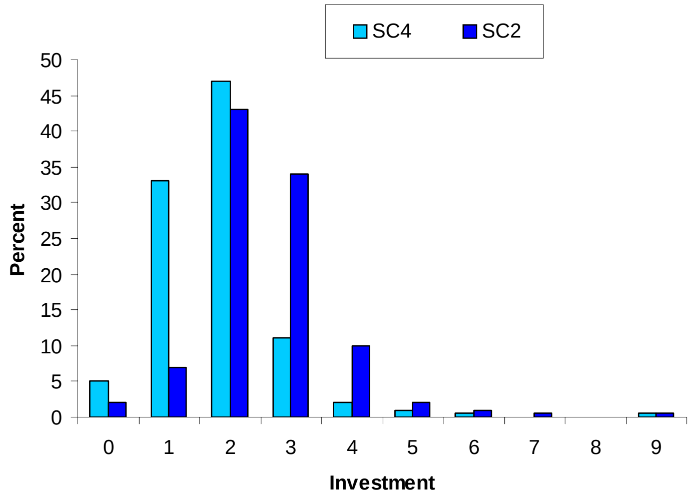

Figure 2: Investment distributions under SC.

Table 1: Subject distributions under SC.

Interval	$[0,1)$	$[1,2)$	$[2,3)$	$[3,4)$	$[4,5)$	$[5,6)$	$[6,7)$	$[7,8)$	$[8,9]$
SC2	0	1	28	6	1	0	0	0	0
SC4	2	20	9	1	0	0	0	0	0

mean investments over the 20 periods between 2 and 3. For SC4, 20 of the 32 subjects have mean investments between 1 and 2.

The observed deviations from the Nash equilibrium are strikingly different from those in standard Cournot oligopoly games where players choose outputs rather than investments. These games are structurally very similar to the reduced version of the investment game, in that they also feature strategic substitutes and negative externalities. Hence, in the Nash equilibrium, players choose more output than under joint-profit maximization. In experiments with few players, subjects collude, that is, choose output levels below the Nash equilibrium and closer to joint-profit maximization. For more players, this result is reversed; output is even higher than predicted in the Nash equilibrium (Huck et al., 2004). Thus, more intense competition leads to less cooperative behavior. For our investment games, this is no longer true, no matter whether one uses the discrete or the continuous game as a benchmark. Relative to the former benchmark, the Huck et al. (2004) results are reversed: Players choose too high levels of the non-cooperative action for SC2, but too low levels for SC4. Relative to the latter benchmark, actions are too high for both SC2 and SC4.

3.3.2 Intense Competition

Next, we consider Hypothesis 2, which is based on the result that the expected investment level in the MSE for IC2 (2.62) is higher than for IC4 (1.27). The experiment provides evidence for this prediction.

Result 3 *Mean investments are higher for IC2 than for IC4.*

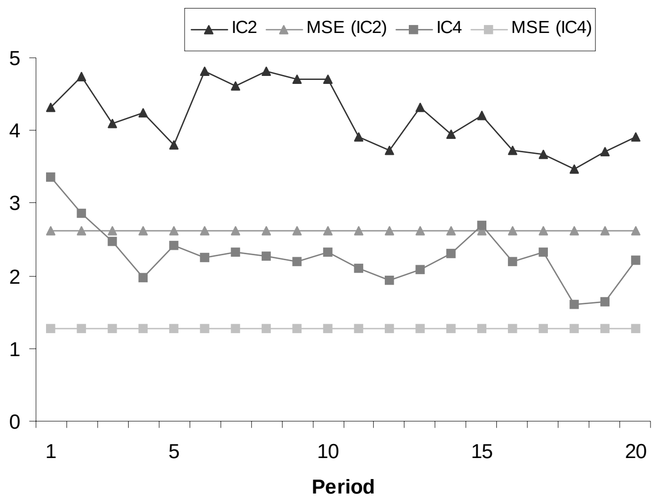

Figure 3: Mean investments under IC.

Figure 3 reveals that the mean investment level under IC2 does not approach the one under IC4. The difference between the two treatments is highly significant over all periods, and even in the last ten or the last five periods.[22]

[22] This holds both for a Wilcoxon rank sum test and for a regression over a constant.

Figure 3 also shows that, both under IC2 and IC4, the mean investments over the 20 periods always lie above the MSE values of 2.62 and 1.27, respectively. In IC2, the difference between investments and the MSE is highly significant throughout the 20 periods. This still holds in the last ten or the last five periods. That is, there is no convergence to the Nash equilibrium value of 2.62, even though the investments in the first ten periods are significantly higher than those in the last ten periods (Wilcoxon rank sum test, $p = 0.016$).

In IC4, considering all periods, a regression over a constant shows that the difference between investments and the MSE is highly significant, whereas a Wilcoxon rank sum test indicates high significance only in the first five periods ($p = 0.01$).[23] However, the investments in the first ten periods are not significantly higher than those in the last ten periods (Wilcoxon rank sum test, $p = 0.146$). Again, there is no convergence to the MSE value of 1.27. In the last five periods, a Wilcoxon rank sum test shows significance at the 4%-level.

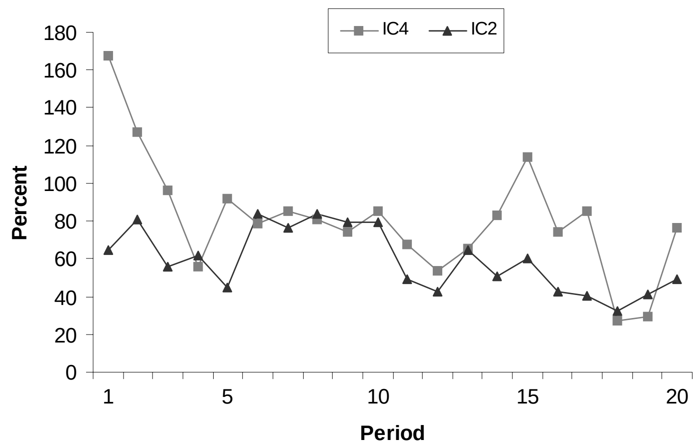

Figure 4: Deviation from the equilibrium under IC.

Inspection of Figure 4 shows that, in IC2 and IC4, the percentage deviations from the theoretical predictions are similar in most periods. Over all

[23] The heterogeneity of investment choices under IC4 explains this discrepancy.

periods, the difference between the two treatments is not significant.

Having provided support for the comparative statics result (Hypothesis 2), we now investigate to which extent the asymmetric pure-strategy equilibria and the symmetric mixed-strategy equilibrium predict behavior within each IC treatment. In both treatments, the investments that are part of the asymmetric pure-strategy equilibria stand out. Even though, unsurprisingly, the players do not coordinate perfectly on such an equilibrium, the two equilibrium strategies are played particularly often.

Result 4 *For IC2, the frequency distribution exhibits a global maximum at 5. There is a local maximum at 0. For IC4, the frequency distribution exhibits a global maximum at 0. There is a local maximum at 5.*

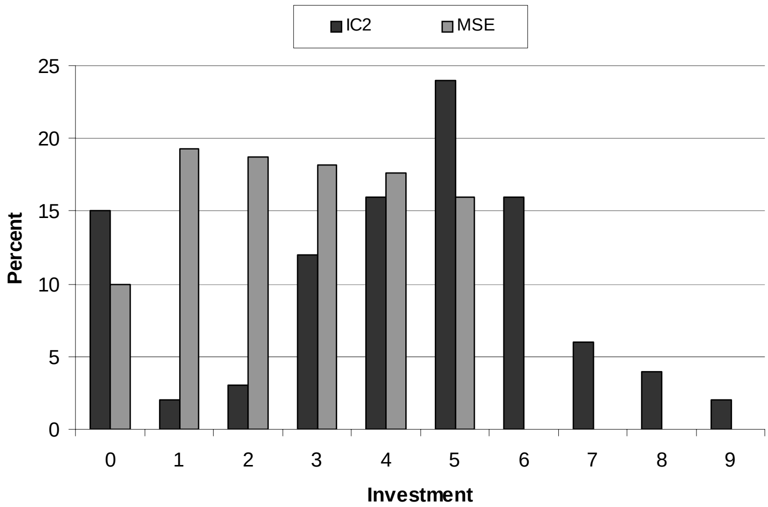

Figure 5: Investment distribution under IC2.

Figure 5 shows that, in IC2, the investment level of 5 is played in 24% and that of 0 in 15% of the cases. Figure 6 shows that, in IC4, the corresponding percentages are 17% and 43%. These qualitative properties show up clearly in almost every individual period.[24]

[24]For IC2, in 19 periods, the investment distribution exhibits a global maximum at 4 or 5. In 15 periods, there is a local maximum at 0. For IC4, in each period, the investment distribution exhibits a global maximum at 0 and a local maximum at 4 or 5.

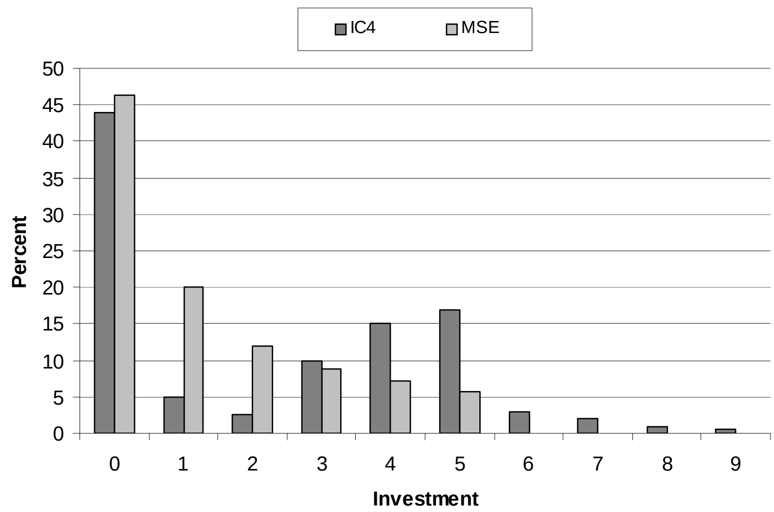

Figure 6: Investment distribution under IC4.

The next results concerns the relation to the MSE.

Result 5 *For IC2 and IC4, the MSE predicts the percentage of zero investments very well, but underpredicts the percentage of subjects who choose high investments.*

In both cases, low non-zero investments are chosen much less than predicted, and high investments more often. Figure 6 reveals that the MSE predicts the percentage of zero investments very well. However, also for IC4, overinvestment is substantial. The investment levels of 0, 1, and 2 are chosen less often than predicted; those from 3 to 9 more often than predicted.

Interval	$[0,1)$	$[1,2)$	$[2,3)$	$[3,4)$	$[4,5)$	$[5,6)$	$[6,7)$	$[7,8)$	$[8,9]$
IC2	1	1	6	6	11	6	2	1	0
IC4	8	9	7	4	7	1	0	0	0

Table 2: Subject distributions under IC.

Table 2 shows that the heterogeneity of investments reflects heterogeneity across players. For IC2, except that there is no local maximum in $[0,1)$, the distribution of the average investments is similar to the distribution of Figure

5. For IC4, except for the fact that the global maximum arises in $[1, 2)$ instead of $[0, 1)$, the distribution is similar to that of Figure 6.

To sum up, the number effects predicted by Hypothesis 2 are reflected quite well in the data. The point predictions of both types of equilibria are imperfect. Roughly speaking, the observed behavior corresponds to a mix between the symmetric mixed-strategy equilibrium and the asymmetric pure-strategy equilibrium.

3.3.3 Soft versus Intense Competition

We now turn to Hypothesis 3. We shall show that investments are higher in both IC treatments than in the corresponding SC treatments, even though the MSE predicts this only for SC2, in which case the equilibrium investments both for the discrete (2) and continuous benchmark (2.4) are lower than for the MSE under IC2 (2.62). The experiment provides evidence for this prediction.

Result 6 *As predicted, mean investments are higher for IC2 than for SC2.*

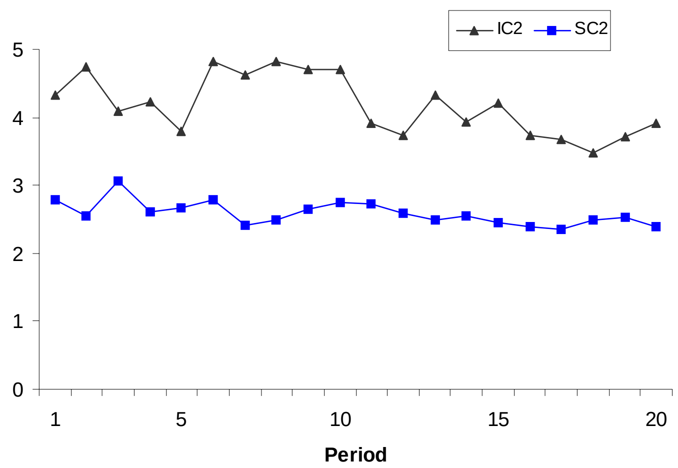

Figure 7: Mean investments for IC2 and SC2.

Over all periods, the difference between mean investments in IC2 and SC2 is highly significant. Figure 7 shows that the mean investment level under

IC2 does not approach the one under SC2. Even in the last five periods, the difference remains highly significant.

While the comparative statics observation is consistent with equilibrium behavior, Figure 7 reveals that the higher investment in IC2 is reinforced by behavioral effects. In each period, overinvestment, measured as the percentage by which mean investments exceed the corresponding equilibrium value, is greater in IC2 than in SC2. The difference is highly significant when taking into account either all periods or the last five periods.

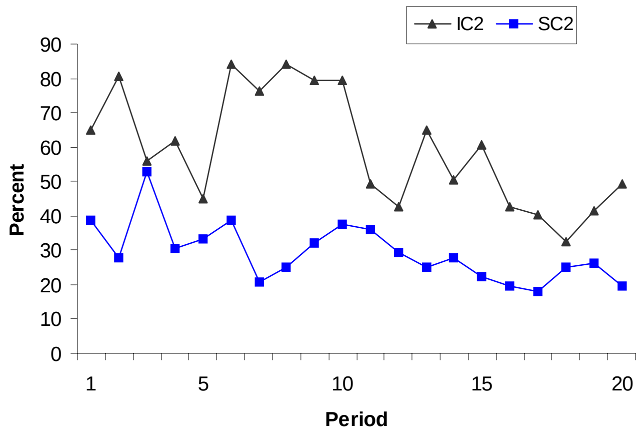

Figure 8: Deviation from the equilibrium for IC2 and SC2.

Interestingly, in the four-player case, the behavioral effects are so strong that they overturn the comparative statics prediction of Hypothesis 3, which was based on the observation that the equilibrium investments both for the continuous (1.69) and discrete benchmark (2) in SC4 are higher than for the MSE in IC4 (1.27).

Result 7 *Contrary to the prediction, mean investments are higher for IC4 than for SC4.*

Figure 9 shows that, except for period 18 and 19, the mean investment level is higher in IC4 than in SC4. Taking into account all periods, a regression over a constant shows that the difference between the two treatments is highly significant. However, a Wilcoxon rank sum test indicates significance at the 10%-level only in the first ten periods. Mean investments under IC4 seem to converge to those under SC4. However, a regression over a constant and a Wilcoxon rank sum test lead to different results. Considering the last five periods, the former shows no significant difference between the two treatments, whereas the latter exhibits significance at the 4%-level.[25]

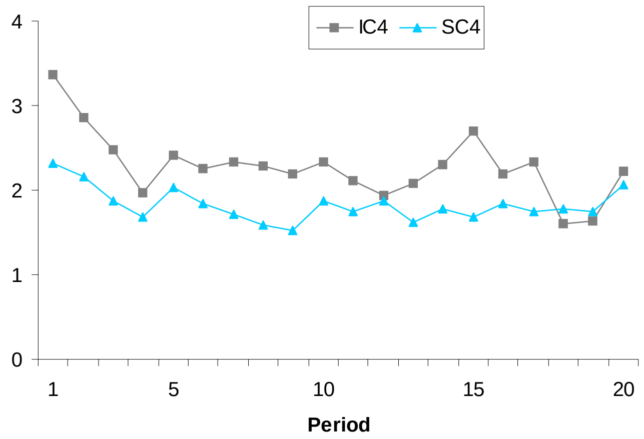

Figure 9: Mean investments for IC4 and SC4.

To sum up, investments are higher for IC than for SC, even in the four-player case where this does not correspond to the Nash prediction. Essentially, this results because the tendency to overinvest is more pronounced for IC than for SC.

3.3.4 The Efficiency of Investments

It is intuitively clear that the tendency to invest more than in the Nash equilibrium cannot be beneficial for firms. In this section, we measure the efficiency relative to joint profit maximization (JPM). Of course, this efficiency notion only considers the firms' interest. If consumers' interests were

[25] Again, due to the heterogeneity of the investment choices, which is generally more pronounced for IC than for SC, the statistical analysis is not unique.

taken into account, the overinvestment would have to be interpreted as an efficiency-increasing deviation from the Nash equilibrium.

For IC, the maximal joint net payoff is achieved in each asymmetric pure-strategy equilibrium;[26] for SC, the joint profit maximization benchmark implies lower investments than the Nash equilibrium. Intuitively, investments impose a negative externality on the other players.[27] In all treatments, players overinvest relative to the JPM. To measure the extent of deviation from JPM, consider the efficiency rate (ER), defined as

$$ER = \frac{\textit{Mean Joint Net Payoff}}{\textit{Maximal Joint Net Payoff}}.$$

The ER considers the joint net payoff over all periods and groups in relation to the maximal joint net payoff. For IC, negative values emerge, which reflect the inefficiency resulting from overbidding. Under IC2, a value of -0.69 arises; under IC4, -0.87. The participants made losses over the 20 periods. In IC2, 22 of the 34 subjects earned a negative net payoff in at least 14 periods. In IC4, 13 of the 36 subjects earned a negative net payoff in at least 13 periods. No subject earned more than the initial endowment at the end of the IC sessions. On the other hand, the SC cases are relatively efficient. The SC2 treatment leads to an ER of 0.91. For SC4, the value is 0.77. Each participant earned more than the initial endowment.

4 Conclusion

This paper has analyzed the effects of more intense competition on investments in an experiment where a reduced form version of a simple two-stage R&D model has been implemented. In the first stage, firms whose marginal costs are identical ex-ante simultaneously invest in R&D. The investment leads to a decrease in marginal costs. In the second stage of the game, firms simultaneously choose quantities or prices in a homogenous good market.

When more intense competition is modeled as an increase of the number of firms for a given type of product market competition, the theoretical prediction is that, both for SC and IC, an increase in the number of agents yields

[26] As that this equilibrium strategy has one player investing and considering that this player maximizes his own net payoff by choosing the investment level of 5, it follows that also the joint net payoff is maximal.

[27] For SC2, it can be shown that the maximal joint net payoff arises when the two players choose the investment level of 1; under SC4, when one player chooses 1 and the others 0.

lower mean investments. This hypothesis is confirmed in the lab. When more intense competition is modeled as a switch from Cournot to Bertrand competition, the observed investments increase, even though the MSE only predicts this in the two-player case.

An important limitation of our analysis concerns the very long run. As overinvestment tends to coincide with negative earnings in the IC game, it is not sustainable. Thus, in the very long run, firms must either adapt their behavior or they will disappear from the market. This feature is much less pronounced in the SC game, where overinvestment is compatible with positive earnings. One might therefore conjecture that, in the long run, whereas overinvestment remains in the SC case, it disappears in the IC case.

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